

Photometrically simply behaving mCP stars

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Abstract. We analyzed *ubvy* and H_p light curves of 19 well observed magnetic CP stars selected from the *On-line database of photometric observations of mCP stars* of which light curves in all the five colours were similar. We assumed that among these photometrically simply behaving (PSB) stars could be found such ones which have a single photometric spot. The insight into such simple situations would help us to comprehend more complicated cases.

Light curves of the 19 PSB mCP stars proved to be generally nearly symmetric but surprisingly diverse. The analysis shows that only in the case of HD 110956B, HD 188041, and perhaps HD 193722 we are able to explain their photometric behaviour by a simple one-spot model. Consequently, occurrence of more than one photometric spot on an mCP star is typical.

Key words: chemically peculiar stars – light curves – methods

1. Introduction

It is generally accepted that the rotationally modulated photometric variability of magnetic CP stars originates in consequence of non-uniform horizontal structure of their atmospheres induced by strong global magnetic field and uneven surface distribution of chemical elements.

Recently we successfully simulated the observed light variability of the He-strong CP star HD 37776 in *ubvy* colours providing an inhomogeneous elemental horizontal distribution. Despite this star displays a relatively complex surface pattern with several relatively bright and/or dark regions (see Krtička *et al.* 2007) and a quadrupole dominated magnetic field (Thompson, Landstreet 1985), its light curve shows a not very complicated single wave form. However, HD 37776 is not a typical representative for its considerably complex magnetic field geometry which can make the stellar surface a bit disordered. A still better subject could be another Si star, HD 177410, (Krtička *et al.* 2008, these proceedings) with only two bright spots on the surface, and we do not exclude the existence of mCP stars with even simpler photometric structure having only one dominant spot tied with spectroscopic or magnetic structures on their surfaces.

In this brief recognition study we attempt to look up and study mCP stars which could carry on such easily readable surface structures. The comprehension of the simplest case can be a way to common, more complicated ones.

2. Photometrically simply behaving mCP stars

We showed (Mikulášek *et al.* 2007a) that the variable part of a light curve (LCs), Δm_c in the colour c of an mCP star, can be expressed as a linear combination of two normalized orthogonal phase functions $f_1(\varphi), f_2(\varphi)$, which can be found easily by means of the advanced principal component analysis (Mikulášek, 2007):

$$\Delta m_c(\varphi) \cong A_{1c} f_1(\varphi) + A_{2c} f_2(\varphi); \quad (1)$$

$$\sum_{j=1}^N f_1^2(\varphi_j) = \sum_{j=1}^N f_2^2(\varphi_j) \cong \frac{N}{2}; \quad \sum_{j=1}^N f_1(\varphi_j) f_2(\varphi_j) = 0, \quad (2)$$

where N is the number of measurements, φ_j is phase of the j -th measurement.

We quantify the similarity of two colour light curves by a ratio

$$r^2 = \sum_{c=1}^5 A_{2c}^2 / \sum_{c=1}^5 A_{1c}^2, \quad (3)$$

and we adopt that light curves of an mCP star are mutually similar if $r < 0.15$. In such a degree of similarity the light curves can be described sufficiently by a unique phase function, which mathematically means the second term in Eq. 1 can be neglected.

Out of the 85 stars with known ephemeris and the *uvby* and H_p photometries contained in the *On-line database of photometric observations of mCP stars* (Mikulášek *et al.*, 2007b) only 19 mCP stars satisfied the above-mentioned criterion of the similarity: two He-weak, twelve Si, and five SrCrEu-type stars. It is rather surprising that shapes of their LCs are very diverse (see Fig. 3), what can be also documented by the following quantification. We assume the phase function $f_1(\varphi)$ in the form:

$$f_1(\varphi) = \sqrt{1 - a_1^2 - a_2^2} \cos(2\pi\varphi) + a_1 \cos(4\pi\varphi) + a_2 \sin(4\pi\varphi). \quad (4)$$

If the timing of the linear ephemeris is set so that the term with $\sin(2\pi\varphi)$ is zero, then the basic extrema of the LCs occur near phases 0 and 0.5. The variable part of the LCs of a PSB star is then characterized by a set of amplitudes A_{1c} which can be arranged into a vector $\vec{A} = [A_{1u}, A_{1v}, A_{1b}, A_{1H_p}, A_{1y}]$, and by the two parameters a_1, a_2 from equation 4. A light curve characterized by $a_1 > 0$ has a sharper maximum at the phase 0 and a flatter minimum (see e.g.

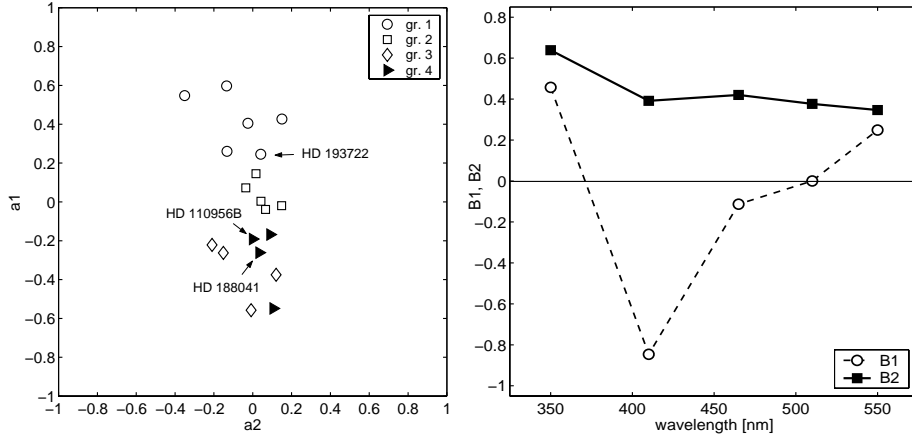


Figure 1. Left: The relation of LCs' parameters a_1 and a_2 , shows that LCs of our PSB stars are only slightly asymmetric. LCs can be divided into four groups. Three stars whose LC's can be interpreted by the one-spot model are denoted with their HD names. **Right:** Two basic dependencies of LCs' amplitudes on the effective wavelength.

HD 197322) and vice versa for $a_1 < 0$. The parameter a_2 expresses the measure of asymmetry of an LC. The larger $|a_2|$ the larger asymmetry. The relation between parameters a_1 , a_2 is depicted on Fig. 1 left.

The components of the amplitude vectors \vec{A} of a PSB star are not independent. They can be expressed by a linear combination of two basic normalized vectors \vec{B}_1 , \vec{B}_2 (courses of $B_{1,2}(\lambda)$ – see Fig. 1 right, where the wavelength λ denotes the maximum transmissivity of a photometric filter concerned) with coefficients A_1 , A_2 , namely $\vec{A} = A_1 \vec{B}_1 + A_2 \vec{B}_2$. For the relationship of parameters A_1 and A_2 see Fig. 2. This indicates that there are at least two different mechanisms responsible for the contrast of a photometric spot in respect to the surrounding stellar surface. Consequently, there exist at least two types of photometric spots on the surface of an mCP star differing in their colour grades. These spots can of course positionally coincide what can either strengthen or suppress their resulting contrast in particular photometric colours.

The first mechanism which is obviously effective in all types of mCP stars creates bright spots in *uvby* due to redistribution of energy from the UV region to the optical one originating at least partly in bound-free transitions of overabundant ions. In hot CP stars the most important elements seems to be silicon, iron and helium. The symptomatic feature of this mechanism is the monotonous decline of the amplitude of light variations B_2 with the increasing effective wavelength as shown on Fig. 1 right. The effect is well reproduced by our models (Krtićka *et al.* 2008, these proceedings).

The second mechanism, manifesting itself through strong variations of the c_1

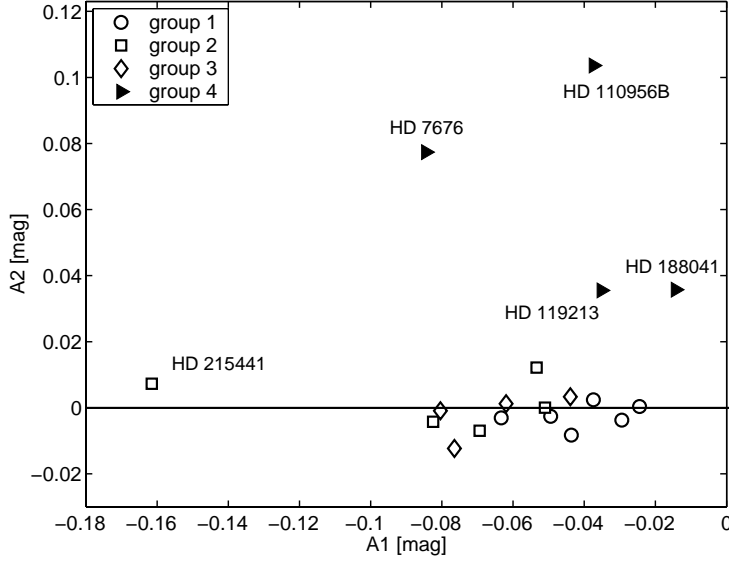


Figure 2. The relation between the effective amplitudes A_1 and A_2 , corresponding to \vec{B}_1, \vec{B}_2 . The late mCP stars (gr. 4) strongly differ from other PSBs.

index, characterizing the height of the Balmer jump, is present only in the coolest mCP stars. The photometric spots caused by this mechanism are markedly dark in the v colour, in which the largest light variations are observed. We speculate that the strong opacity caused by various overabundant elements in a cool atmosphere suppresses the Balmer jump. The purest example of the light variations controlled by this mechanism is HD 110956B with the largest amplitude among all mCP stars (see Fig. 3).

3. Parametrization and classification of PSB stars

The set of the $uvby$ and H_p light curves of each of the PSB stars can be satisfactorily well described by the quaternion of parameters: $\{a_1, a_2, A_1, A_2\}$.

According to these parameters we sort out all the PSB stars into four groups.

- **Group 1:** $A_2 \cong 0$, $a_1 \geq 0.24$, double wave LCs with two unequally prominent bright spot centered on the phases $\varphi = 0$ and 0.5 . Example: HD 177410.
- **Group 2:** $A_2 \cong 0$, $|a_1| \leq 0.24$, single wave LCs. Example: HD 215441.
- **Group 3:** $A_2 \cong 0$, $a_1 \leq -0.24$, double wave LCs with two unequally prominent bright spots centered on the vicinity of $\varphi = 0$. Example: HD 49333.

- **Group 4:** $A_2 \neq 0$, cool CP stars with the largest variations in v caused by a dominating dark spot (see HD 110956B) with a minimum near $\varphi = 0.5$. Besides this, another dark, as in HD 7676, or a bright spot, as in HD 119213 can be present on the surface.

4. Conclusions

All the stars with asymmetric LCs (e.g. HD 171247), as well as all the stars with doublewave LCs (groups 1 and 3) must be left out from the short list of the 19 candidates which LCs can be explained by the simple one-spot model. Similarly, all the stars of the group 2 with $a_1 < 0$ must be deleted as they have two or more undistinguished bright spots centered on the $\varphi = 0$. Thus out of the stars in the groups 1, 2 and 3 only the Si-star HD 193732 is the candidate to be explained by the simple one-spot model. Our analysis of the light curves produced by the one-spot model shows that for $a_1 < 0.15$ the spot covers almost the whole hemisphere of a star.

HD 188041 and HD 110956 are the candidates in the group 4. However, it should be noted, that the dominant photometric spot can, due to geometry, suppress the visibility of another spot.

We conclude that the presence of two or more photometric spots on the mCP stars is quite typical. It seems that the photometrically simply behaving stars do not differ from the others and their belonging to the privilege group is more likely only the consequence of the distributions of spots on the surface with respect to the rotational axis.

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References

- Krtićka, J., Mikulášek, Z., Zverko, J., Žižňovský, J.: 2007, *Astron. Astrophys.* **470**, 1089
- Krtićka, J., Mikulášek, Z., Zverko, J., Žižňovský, J.: 2008, These Proceedings, p. XXX
- Mikulášek, Z.: 2007, *Astron. Astrophys. Transactions* **26**, 63
- Mikulášek, Z., Zverko, J., Krtićka, J., Janík, J., Žižňovský, J., Zejda, M.: 2007a, in *Magnetic Stars*, eds.: I. I. Romanyuk and D. O. Kudryavtsev, SAO RAS, Nizhnij Arkhyz, in press
- Mikulášek, Z., Janík, J., Zverko, J., Žižňovský, J., Zejda, M., Netolický, Vaňko, M.: 2007b, *Astron. Nachr.* **328**, 10
- Thompson, I. B., Landstreet, J. D.: 1985, *Astrophys. J., Lett.* **289**, 9

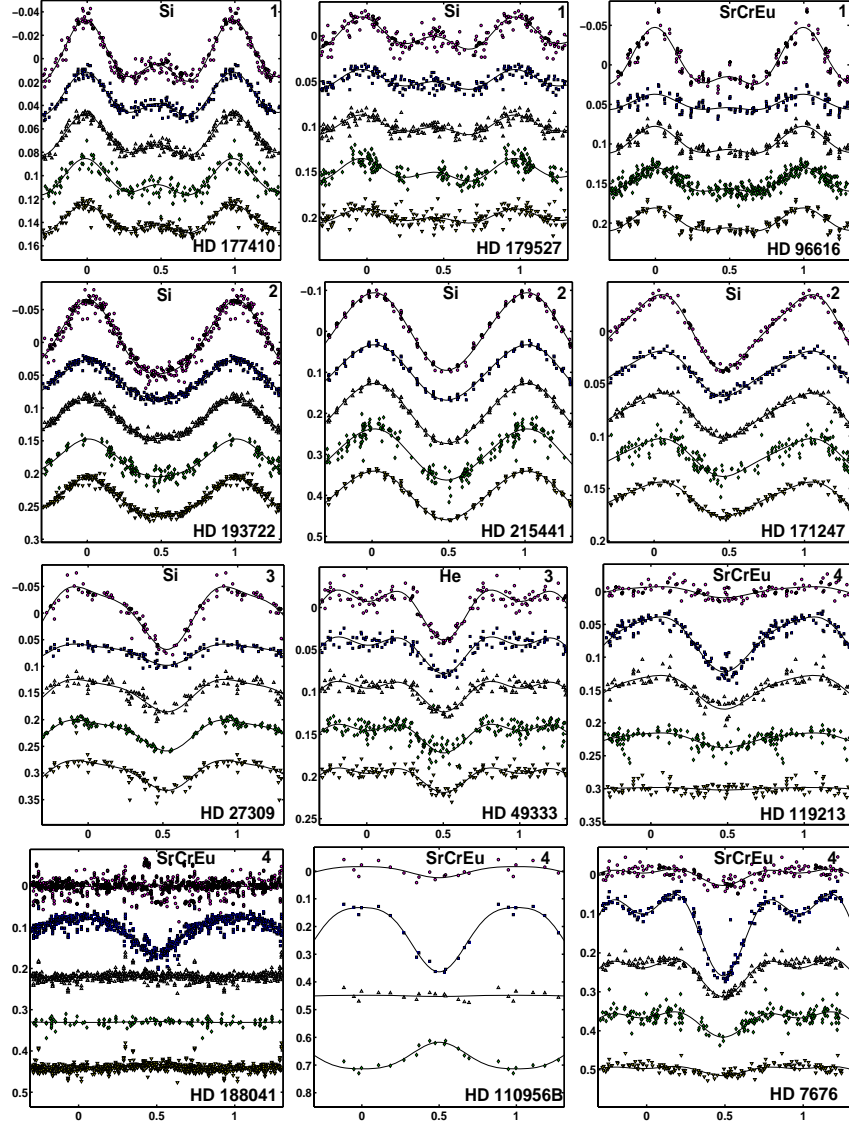


Figure 3. Light curves of 12 out of the 19 photometrically simply behaving mCP stars. In each panel there are displayed u, v, b, H_p, y light curves, the name of the star, its CP spectral type and the number of the photometric group.